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## POSITIVE AFTER-IMAGES OF LONG DURATION

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### A. SUCCESSIVE COLOR INDUCTION

I. *Of an owl (Glaucidium whitelyi Sws.).* During the day the owl generally slept on its perch, which was a bar of wood passing through its cage at about five inches from the floor. In the night the bird frequently sprang from the perch onto the tin floor of the cage. It usually walked each time for many minutes to and fro on the tin floor, but it always hopped quickly onto its perch where it remained for some time, at least many seconds and often a few minutes, whenever I made an unusually loud noise in the room. The owl could fly, but it nevertheless always hopped, as is characteristic of many small owls, onto its perch. I wish here to emphasize the fact that the owl was never observed to miss its perch when it sprang at it, and it was moreover never observed to spring from one place to another on the floor; it walked on the floor and sprang off and onto the perch.

The following experiments with the owl were performed always at night in a room which was so dark that a human being could barely perceive white objects after long adaptation to the darkness.

As the owl stood, relative to my position, to the right of its perch and with its breast and head turned toward me, I turned on the electric light. The animal remained motionless on the floor and fixated my face until I beat a table with a ruler thereby making a loud noise. As usual it then sprang onto its perch. I turned out the light and waited until it was again in its previous position on the floor, and this time I turned the light as rapidly as possible on and off while the owl stood quite motionless and fixated my face. After I had thus illuminated the bird six or seven times I beat against the table with the ruler. I distinctly heard the owl leave the floor and then fall on the tin; the owl hopped, but this

time it missed its perch. I turned the light on and found the animal still on the floor, but this time its back was turned toward me. In order to fixate me now it turned only its head almost  $180^\circ$  and to the left, i. e., anti-clockwise. While it stood in this position and fixated my face I turned the light repeatedly on and off in the tempo of about 0.5 sec. Immediately after the sixth illumination I beat against the table with the ruler. I again heard the owl hop on the tin floor and when I turned on the light I found it had really missed its perch and had indeed sprung in just the opposite direction; it sprang away from and came to rest with its back turned to the perch. Its right side was now turned to me. The two hops served to turn the bird clockwise almost  $270^\circ$ . In order now to fixate me, the owl turned only its head not to the left as before, which would this time have meant through almost  $270^\circ$ , but to the right, i. e., through an angle of a little more than  $90^\circ$ . I illuminated it as usual and after the sixth illumination I beat the table with the ruler. This time, however, the owl did not spring, but, as I could distinctly hear, it walked about rapidly on the tin floor. When I turned on the light I found the animal walking about excitedly to and fro and acting as if it were trying to get through the bars of its cage. Shortly it hopped onto its perch. Under the same conditions the thus far described reactions were, with only very insignificant variations, repeatedly obtained.

The cage was next turned so that the owl could be illuminated while it stood to the left of the perch. I illuminated it and then scared it just as before, and its reactions were the same as the previously obtained ones, with the single exception, however, that the two hops always served to turn the animal in the direction opposed to that of the hand of a watch.

The cage was then turned so that the perch was directly behind the owl; as the owl fixated me, no part of the perch was in its field of vision. As usual I illuminated it six times and then beat the table, and *without exception* the owl sprang onto its perch.

To obtain still another variation, I waited until the bird chanced to stand on the floor at the back part of the cage when I could see its eyes either below or above its perch. I illuminated it as before and made the noise with the ruler. Very often it succeeded in hopping onto its perch, but a few times it sprang too high and fell on the tin floor near the front of the cage and at other times it apparently jumped against the perch and of course fell back onto the floor.

The above experiments were repeatedly performed with

modifications in so far as the number, duration, or tempo of the illuminations was varied. It seems to be the case that six illuminations were as good as ten or twenty. It became furthermore evident that it was not at all essential to beat the table immediately after the sixth illumination; for when I waited 25 sec. to beat, the owl also missed its perch regularly and indeed even after a lapse of 40 sec. the erroneous response was sometimes made.

When the owl made the first mishop I supposed the light had blinded it to such an extent that it could not see the perch, but this assumption proved to be of no value; for without exception when the owl could not see the perch while being illuminated, it made no erroneous hops. Only when a portion of the perch was in the owl's field of vision did mishops occur.

In order to explain these peculiar reactions I made the assumption that at the time I beat with the ruler the owl had a distinct after-image of the perch, which it responded to more strongly than to the real perch, i. e., the attempt was to hop onto the after-image instead of the perch itself. If this assumption deserves to be entertained we must suppose that the owl had, as a visual after-effect, something much more definite than a mere after-sensation; it must have been an unusually distinct after-image, which, with respect to form and color, was so similar to the illuminated perch that the owl might easily mistake this after-image for the perch. Otherwise expressed the after-effect must have been a strong positive after-image which of course wandered with the eye movements.

For those who have made no special study of owls, it may be here necessary to make the following explanation: Before an owl flies or hops (when excited some small owls hop) away from an enemy it faces, it usually first turns its head to the right or to the left as though it were looking for a new place to go. It may turn its head in the one and then in the other direction many times before it suddenly turns also its body as it flies away. Whenever the enemy remains unnoticed until it is very near, or, when a noise near the owl is very loud, the head is first turned, but it is nevertheless often *still* turning when the owl hops or flies away.

We are perhaps now in position to understand the described reactions of our owl:

Case 1. While the breast and face of the owl were directed toward me as I stood to the right of the perch, a part of this perch fell in the bird's field of vision. After I ceased illumi-

nating, this part and the positive after-image of it were coincident until the owl turned its head in the direction of the combination of perch and after-image, then the latter was shifted to the right and since it was a peripheral after-image it continued to shift and was still shifting when the owl reacted to it by hopping. The attempt to hop onto the shifting positive after-image resulted in the bird's turning through an angle of almost  $180^\circ$  in the direction of the hand of a watch, and of course in its falling on the floor. We must not forget that the owl did not stand long and watch the after-image shift as the head turned; it hopped while the head was still turning.

Case 2. The owl then stood with its back and face turned to me. I illuminated it and then beat the table. Preparatory to the springing the head was first turned in the direction of the perch, but the tendency to follow the shifting after-image caused the head to finally move through the large angle of about  $270^\circ$ . Since the body was already turned almost  $180^\circ$ , it was this time easier for the bird to turn the head farther than before and thus cause the after-image to shift about  $90^\circ$  farther to the right than in Case 1. The animal tried to hop onto the shifting after-image and fell.

Case 3. The owl stood to the right of the perch with its right side turned to me, and, in order to fixate me, it turned its head a little more than  $90^\circ$  instead of almost  $270^\circ$  as it would have been compelled to do if it had moved to the left as before. When I this time beat the table the owl turned its head allowing the face to pass over the breast. The after-image was necessarily thrown through the bars and the owl did not often try to spring through these bars, which it could see even though it was dark; its response was that of walking to and fro as near as possible to the place where it last saw the after-image.\*

Case 3a. This time the owl stood to the left of the bar and was illuminated. It made the same general responses as it did in the Cases 1, 2 and 3, but the first two hops served to turn the body in the direction *opposed* to that of the hand of a watch. When the owl turned its head in the direction of the combination of perch and after-image, the latter was this time

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\* The bird subjects mentioned in this paper were specimens from the Zoological Garden in Berlin, Germany, and were kindly furnished me for research purposes by Prof. Heck, the director of the garden. The experiments with them were performed in my private research rooms in Charlottenburg-Berlin, from July 1, 1914 to Sept. 1, 1915. The experiments with human beings were in most cases first roughly performed in the animal rooms and then more systematically in the psychological laboratory of the University of Berlin.

necessarily shifted in the direction *opposed* to that of the hand of a watch; the owl followed this after-image when I beat the table the first two times. When I beat the third time, the conditions were analogous to those in Case 3, and the owl's response was consequently the same as before (Case 3); it walked to and fro along the bars.

Case 4. The owl stood directly before the perch and fixated me; no part of the perch fell in the owl's field of vision. Since there was no occasion for a response to an after-image as before, the owl succeeded each time in hopping onto the real perch.

Case 5. The owl stood in the back part of the cage and had me and also the perch in its field of vision. When I beat the table the owl made few mishaps, but it nevertheless sprang occasionally too high or too low. The perch and the after-image were evidently not always coincident as the bird left the floor; the after-image was thrown, owing to movements of raising or lowering the head immediately before the hop was taken, sometimes above and sometimes below the perch.

II. *Of a cockatoo (Cacatua gymnopsis Scl.)* Corresponding results were won from the cockatoo. While in artificial light, in daylight or in the twilight this expert climbing bird walked back and forth on its perch and never made a misstep. In the dark it walked, if at all, quite slowly and very little, as compared with what it did at other times, but even under the condition of darkness it never fell from its perch. It often walked without speaking, but as it talked it generally walked.

I placed an electric light just outside the cage and near one end of the perch, which was a rounded stick of wood attached to two sides of the cage. As the cockatoo stood on the distal end of the stick from the light I illuminated it as I did the owl. I illuminated it six times and then spoke to it; it began to speak just as in the daytime, but often before it had completed the first word it fell backwards from off its perch.—The cockatoo can see very little if at all in the dark; therefore when I spoke to it and it made the usual response of talking it of course started to walk to the other end of the perch, *i. e.*, in the direction of the extinguished light. Perhaps, however, it could not see the perch but only the positive after-image of it. When it started to walk it turned its head in the direction of the extinguished light and thereby caused the after-image to shift, and with respect to the bird's body, in the backward direction. It took a step to grasp this after-image,

which was no longer coincident with the perch, and quite naturally lost its equilibrium and fell backwards. It made no difference which side of the cockatoo was illuminated; it always fell backwards when it stood, while being illuminated, on the distal end of the perch from the light. I often noticed that the bird, after it had lost its equilibrium, was still holding the perch with one foot; this was always the foot most distant from the light.

When the cockatoo stood on the end of the perch near the light and was illuminated as before, it never fell. It behaved in this case just as it usually did when I spoke to it in the dark. It spoke very slowly and also very little, and instead of walking about on its perch, it merely threw the weight of the body first on one foot and then on the other. The failure of the bird to respond as vigorously as in the previous experiment was due to the fact that the shadow of the bird's body fell on the perch; for when I left the bird in its position and placed the light at the other side of the cage, the erroneous step was again taken.

The missteps of the cockatoo did not occur as regularly as the mishaps of the owl, but this is evidently due to the fact that the cockatoo did not remain as quiet as the owl while being illuminated. It was also the case that the after-images of the cockatoo did not persist as long as those of the owl; for when I spoke to it 25 sec. after the last illumination, it behaved as it usually did in total darkness. When I waited only 20 sec., however, it very often fell from its perch.

*III. Of human beings.* Although the conditions of the experiments were apparently just the same for me as for the birds, I was nevertheless unable to observe positive after-images of long duration. I took great care, however, to remain as motionless as the owl, while I illuminated myself (and of course the objects about me) just as I did the birds, and finally I observed a positive after-image of my hand, but this was of only two or three seconds' duration. But one time I waited about five seconds after the sixth illumination and then illuminated my hand only once. This time I could scarcely convince myself that the light was not still burning; it seemed as if I could see my real hand, the real objects on my table and even the pictures on the wall. These decidedly positive after-images persisted for many seconds, and when I turned my head, they were shifted just as I supposed was the case with the birds. Since this time, I have often observed these after-images for forty seconds and one deter-

mination with the stop-watch shows that one positive after-image of my hand persisted for 54.4 sec. (I tried the new method on the cockatoo and found that it more frequently made the missteps.)

Since I have had much practice in remaining still while being illuminated, I am at the present time able to observe very distinct positive after-images of long duration even though I illuminate myself only once, but a necessary condition for the observation is that I remain for a few minutes in the dark.

When I fixate with both eyes and then close them carefully after the last illumination, it is often difficult for me to believe that they are really closed. Observers often exclaim, "My eyes won't shut," "I've lost control of my eyelids," etc. This illusion is evidently due to the fact that the after-images, which have the same appearance, as far as color and form are concerned, as the illuminated objects, are not only just as distinct as when the eyes are open but usually much more so.—Another very peculiar illusion is to be noticed when the observer, while being illuminated, fixates with only one eye, e. g., with the right one, and then opens also the left eye. It often seems as if through some painless procedure the left eye were being pulled out of the head. Some of the observers related their experiences in the following ways: "I can't see with the eye that was closed," "I am blind in that eye," "It feels as though that eye were falling out," "I have a very peculiar sensation in that eye, but just what's happening to it I can't exactly say," etc.

It is to be noticed that when any part of the body makes a sudden movement, the positive after-image suddenly disappears. This is without doubt connected with the fact that the after-images observed while the eyes are closed are of longer duration than otherwise; for then such sudden involuntary movements of at least some parts of the visual apparatus, e. g., the eyelids, no longer take place.

After a positive after-image has disappeared, a negative after-effect is often to be observed, but the latter is relatively very indistinct, in so far as it is not characterized by having a definite form. I therefore prefer to speak of the negative after-effect which succeeds the positive after-image, as a negative *after-sensation*. According to my observation the after-sensation is generally not of such long duration as the after-image. It is often to be observed that as soon as the first negative after-sensation disappears a positive after-effect again appears, but this is very weak, indefinite as to form



and of very short duration. This we may also call an after-sensation, and of course a positive after-sensation—We should theoretically conclude that if the observer should once be illuminated at the particular time when the negative after-sensation has run its course and the positive after-sensation is about to appear, the latter would be strengthened to such a degree that it would become converted into an unusually distinct and long lasting positive after-image. This is in fact the case. If the positive after-image lasts, for example, 20 sec., then the experimenter, in order to obtain the most marked effect, should wait about 20 sec. longer and then illuminate the objects in the observer's field of vision once more.

Since it at least in some cases occurs that in successive induction a positive after-image and indeed one of long duration can be brought about as the first after-effect, we should for logical reasons conclude that a phenomenon of fundamentally the same nature must, under proper conditions, also come about in simultaneous induction. Experimental facts, which we shall next discuss, demonstrate beyond a doubt that this is really the case.

#### B. SIMULTANEOUS COLOR INDUCTION (OF HUMAN BEINGS)

The material used for our main experiment is a piece of green paper (any color may be used) of about 4 x 4 inches and a gray background (or even a white one) of about 20 x 20 inches in the central region of which the green paper lies. The observer holds the eyes at a distance of about nine or ten inches from the green paper and carefully fixates a point on it; a point near the center is best. It is also for this experiment necessary for the observer to eliminate through practice many involuntary movements of the eyes and head.

The paper that is being fixated becomes less and less greenish, as is well known, but long before it appears reddish (i. e., provided the observer does not allow the eye-lashes to fall and partially obstruct the vision) the entire background becomes greenish. Green is the first color to be induced on the background by green. Following this first induced color, which is unmistakably green, appears an unmistakable red. The red does not appear first. Red is the last color to be induced when one carefully fixates green. When the red disappears, the background again becomes greenish.

If, when the first induced green on the background is on the verge of disappearing, the green paper is quickly removed to expose a red paper of the same size, which can be before-

hand glued to the background piece, the red on the background becomes in a short time by far more pronounced than if the green paper had remained. (This experiment is essentially the same as one we performed in successive induction, p. 331.

Since the induced color can have the form of the background, we may speak of it as a positive *after-image*. This expression has its advantages, since there are occasions also in simultaneous induction when it is of value to speak of positive and negative *after-sensations*. Some of these *after-sensations* would be the very small indefinitely bordered areas of color which are to be observed on the background after a period of very long fixation.

As is well known a red border develops around the green paper that is being fixated. If the eyes are held very still this border is narrow; if they are allowed to wander, without leaving the paper entirely, it may become very wide, and if the eyes wander to a distant point on the background, one can no longer speak of a border but of a red after-image of the *entire* green paper instead of only the outer edges of it. If in a dark room I illuminate the paper for a *very* short time, I can observe a positive after-image of it, and if I wait until the green after-image disappears, I see red; but it is not at all necessary for me to do just this in order to see the red. I can illuminate the paper for a greater length of time and thereby avoid having to notice the positive after-image; I observe red at once. Moreover I do not need to do just this. I can fixate the illuminated paper for a few seconds and then turn the eyes away from it while the light is still burning; also in this case I observe the red immediately. In view of these facts we must necessarily conclude not only that our red border is due to small involuntary eye movements, as is indeed often supposed to be the case, but also that the red of this border is by no means the first but the last color induced by the fixated green.

Voluntary as well as involuntary eye and body movements play a significant rôle in the case of the Hering window. This window, when recklessly used, is indeed a singular device to blind and deafen one to our general law of color induction which we may now formulate as follows: *In successive and simultaneous color induction, any color induces first itself and last of all its antagonistic color.*

When a green and a white window is used, and the two shadows of a board five inches in width are allowed to fall on a large screen of thin linen, one of these shadows appears

of course green to an observer who stands behind the screen, and ordinarily the other shadow appears to be distinctly red. This judgment would seem to indicate that our law is at least for this case not valid. Fortunately, however, one can, while the windows are closed, fixate a point on the screen where the red shadow would ordinarily be observed, and continue careful fixation until the windows have been gradually opened. In this case the shadow does not appear reddish at first; it is at first merely a dark shadow. Careful observation shows that it becomes in a short time greenish and then reddish. If a point to one side of the shadow is fixated, this shadow becomes greenish still sooner.—These results can best be obtained if the observer sits at a distance of about three feet from and preferably behind the screen. The only advantage in his being behind the screen is that shadows of the observer's body do not also fall on the screen and thus complicate the conditions of the experiment.

Instead of having to open the windows the experimenter can cover them with a cardboard and at the proper time gradually remove this. If the board is suddenly removed, the induced red *generally* appears to the untrained observer at once; if the observer has carefully trained himself to keep the eyes still while he fixates, the red often does not appear suddenly. If the board is allowed to fall on the floor and thereby produce a distinct noise, the induced color *always* (at least always to the untrained observer) makes its appearance immediately. After the observer has heard this noise some few hundred times, it then makes no difference whether the cardboard is merely quickly removed or whether it is allowed to fall from the windows. This means nothing more than that the observer has been trained to make a negligible response to the noise.—If now the cardboard is gradually removed and the observer notices no induced color, he will, however, notice the red in the shadow immediately when the experimenter slaps his hands together, stamps with his foot or fires a gun.

These facts lead us to conclude that the sudden appearance of the induced negative color is usually connected with sudden muscular responses of the observer; these may be (so far as the just mentioned observations indicate) responses to sudden noises or to a sudden change in illumination.

In connection with these statements we must ask ourselves the question why it should not then be the case that, when an observer fixates a hand that is illuminated for a very short time in the dark room, he does not likewise respond to this

change in illumination. I am convinced that he does; for his positive after-image of long duration is indeed analyzable into two positive after-images. The first one of these is so intense and of such short duration, really of such flash-like duration, that it cannot be very carefully observed. However short it is it can nevertheless usually be observed to wane; sometimes, however, it disappears quite suddenly. Only when this one wanes does the second positive after-image appear. The second one generally maintains a constant and too a remarkable degree of distinctness until just a very few seconds before it suddenly vanishes. If the observer moves quickly as soon as the light is extinguished, the first after-image disappears quite suddenly (it does not merely wane as before) and often the second positive after-image cannot be observed at all; instead of it the negative after-effect makes its appearance.

The first positive after-image has been discovered and is being used by the kinematographists. I am convinced that the second one has also been earlier observed and has long been and is still being used by spiritualists. One special fact which would render this after-image of particular interest to spiritualistically inclined persons may best be told by relating one of my own experiences with it. I once illuminated a person in the dark room and observed a distinct positive after-image of him. We then went into a well-illuminated room and talked for about forty minutes. I then went alone into the dark room, remained about ten minutes and then with *closed* eyes illuminated the room once more (a single illumination) and immediately I observed a distinct positive after-image of many seconds' duration of the person whom I had previously fixated. Several of my subjects have had analogous experiences.